Very High Energy Cosmic Rays from Centaurus A

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Centaurus A is the nearest radio-loud AGN and is detected from radio to very high energy gamma-rays. Its nuclear spectral energy distribution shows two peaks, one in the far-infrared band and another at about 150 keV. By assuming the second peak is due to the electron synchrotron emission and the power index for the differential spectrum of the very high energy cosmic ray proton to be 2.7 we show that only pp interaction is responsible for the observed GeV-TeV emission from Centaurus A. We also found that indeed many very high energy cosmic ray protons from Centaurus A can arrive on Earth thus supporting the recent observation of two events by Pierre Auger Observatory.

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I. INTRODUCTION

Centaurus A (Cen A or NGC 5128) is the nearest active radio galaxy with a distance of approximately 3.8 Mpc and redshift $z = 0.002$. Because of its proximity, Cen A is one of the best studied radio galaxies although its bolometric luminosity is not large by an AGN standard. Optically, Cen A is an elliptical galaxy undergoing late stages of a merger event with a small spiral galaxy. From Cen A, sufficiently large amount of photometric data is available to build a well sampled spectral energy distribution (SED). The emission from the nucleus of Cen A has been observed in radio, infrared, X-ray, γ-ray[1–5] and also in the GeV-TeV range[6–12]. Recently the Fermi Large Area Telescope (LAT) has also observed Cen A in the energy range 0.2 to 100 GeV[12]. Observations in different wavelengths show that Cen A has FR I morphology having two radio lobes, non-blazar source with a jet inclination of about 50^0. It has a central supermassive black hole of mass $m_{BH} \sim (0.5 - 1.2) \times 10^8 \, M_\odot$. The nuclear SED shows two peaks, one in the far-infrared band ($\sim 4 \times 10^{-2} eV$) and another at about 150 keV.

High energy γ-Rays are produced due to non-thermal process where the particles are accelerated to ultra relativistic energies. Detection of GeV-TeV photons from Cen A signifies that, Cen A has the potential to produce very high energy cosmic rays. Recently Pierre Auger Collaboration reported a correlation between ultra high energy cosmic rays (UHECRs) and nearby AGN within ~ 75 Mpc. In particular two of these events fall within 3.1^0 around Cen A, thus strengthening the possibility that this object is a strong candidate for UHECR source. By assuming the two events are from Cen A the expected rate of UHE neutrinos in detectors like IceCube are estimated [13, 14]. By using the same hypothesis the diffuse neutrino flux from Cen A are estimated[15]. Also the flux of high energy cosmic rays as well as the accompanying expected secondary photons and neutrinos are calculated from hadronic models[16].

It is logical to argue that the astrophysical objects which are producing UHECRs also produce high energy γ-rays due to interaction of the UHECRs with the background[16–20]. We have to also keep in mind that apart from the hadronic interaction (pp and $p\gamma$) with the background, there are leptonic processes (e.g. electron synchrotron, Inverse Compton (IC) Scattering, etc.) also responsible for the production of high energy γ-rays and efficiencies of both the hadronic and leptonic processes depend on the background particles and/or the magnetic field. By using the currently available GeV-TeV gamma-ray data from Cen A, it has been stressed in the literature that only hadronic interaction is insufficient to explain the two events from Cen A[21].

Our paper is organized as follows: In section 2, we discuss different processes which are responsible for the production of gamma-ray in Cen A and how it is compared with the observed photon spectrum. Section 3 is devoted to estimate the number of events from Pierre Auger Observatory (PAO) and its relation with the CR normalization constant. A summary of the observations of very high energy gamma-rays above 250 GeV by different experiments and calculation of expected events from these experiments are discussed in section 4. We briefly conclude our results in section 5.

II. GAMMA-RAY EMISSION PROCESS

The main mechanisms responsible for production of γ-rays in astrophysical objects are the: synchrotron emission by charge particles (protons and electrons), inverse Compton (IC) scattering of electron by background photons, inelastic scattering of high energy cosmic ray proton with the background protons and the photons, and also the photo-de-excitation of nuclei. Depending on the projectile energy and the nature of the surrounding environment of

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the astrophysical object some or many of the above processes can be effective. Here we study the case of Cen A where we have to analyze which are the most probable mechanisms to produce the high energy γ-rays[22, 23].

In general for mildly relativistic systems like AGNs, proton synchrotron radiation is an inefficient process in comparison to electron synchrotron radiation and the energy loss rate of proton is $(m_p/m_e)^4 \sim 10^{13}$ times slower than the electron. Also emitted photon energy from the proton is $(m_p/m_e)^3 \sim 6 \times 10^9$ times smaller than the photon emitted by the electron of same energy as proton. The above analysis is also true for a relativistic system[24] where proton synchrotron process is suppressed in comparison to the leptonic one. So in this case we neglect the proton synchrotron radiation process as compared to the electron synchrotron one. On the contrary in Gamma-Ray Bursts, where the jet is ultra-relativistic, synchrotron emission by proton can be an efficient process. Also the photo-de-excision contribution to the γ-ray is very small in Cen A environment, so we do not take this into account here. In general, the energetic electrons which are Fermi accelerated in the jet of Cen A can have a power spectrum given by

$$\frac{dN_e}{dE_e} = A_e \begin{cases} \left(\frac{E_e}{E_0}\right)^{-\alpha} & E_e < E_{e,b} \\ \frac{E_{e,b}}{E_0}\left(\frac{E_e}{E_0}\right)^{-(\alpha+1)} & E_e \geq E_{e,b} \end{cases}. \tag{1}$$

The constant A_e has the dimension of $photon/keV/cm^2/s$ and E_0 is the energy normalization constant which can vary depending on the range of energy one considers. The above electrons will lose energy through synchrotron emission and the break in the electron energy $E_{e,b}$ is given by

$$E_{e,b} = \frac{6\pi m_e^2}{\sigma_T \xi_B} \frac{\Gamma^5}{\beta^2} f_{es} \frac{\Delta t^{obs}}{L_\gamma^{obs}}, \tag{2}$$

and correspondingly the break in the photon energy is given by

$$E_{\gamma,b}^{obs} = \frac{27\pi^3 e m_e}{2\sigma_T^2} f_{es}^2 \frac{\Gamma^8}{\beta^4} \left(\frac{1}{2\xi_B}\right)^{1/2} \frac{\Delta t^{obs}}{(L_\gamma^{obs})^{3/2}}, \tag{3}$$

where $\sigma_T \simeq 6.65 \times 10^{-25}\, cm^2$ is the Thompson scattering cross section and $\beta = [(\Gamma^2-1)/\Gamma^2]^{1/2}$. Also Γ, ξ_B, Δt^{obs} and f_{es} are respectively the bulk Lorentz factor within the jet, fraction of energy carried by the magnetic field, observed time variability and ratio of shell expansion time to synchrotron emission time which is given by

$$f_{es}(E_e) = \begin{cases} \frac{E_e}{E_{e,b}} & E_e < E_{e,b} \\ 1 & E_e \geq E_{e,b} \end{cases}. \tag{4}$$

The L_γ^{obs} corresponds to the observed luminosity in the observed range of photon energies.

With the synchrotron self-Compton model, M. Chiaberge et al. have reproduced the whole nuclear emission of Cen A by taking the bulk Lorentz factor $\Gamma \leq 3 - 5$ and these values are consistent with the mildly relativistic[25, 26] or a little more [27] proper motions observed on sub-parsec scales[28]. Also in ref.[29] using SSC model they estimate the $\Gamma < 2.5$ in parsec scale. The observation of Cen A during 1973 to 1983 in X-rays below 100 keV has shown greater than an order of magnitude variation on time scales of years [30–32]. Later observations have also shown variability on similar timescales [33, 34] but no high luminosity state was detected since 1985.

In the present work we assume that the second peak at 150 keV in the nuclear SED region is solely due to the electron synchrotron emission in the nuclear region of Cen A and we use the energy normalization $E_0 = 100$ keV [35]. The free parameters in the electron synchrotron model are Γ, ξ_B, Δt^{obs} and f_{es}. But from the above discussions we know that jet in Cen A is mildly relativistic and around 100 keV range the time variability is of order years. In order to fix the observed photon energy $E_{\gamma,b}^{obs} = 150$ keV by synchrotron emission we take the parameters $\Delta t^{obs} \simeq 1\, yr$, $\Gamma = 4.2$, $\xi_B = 0.2$ and $f_{es} = 0.1$. The two parameters $\Gamma = 4.2$ and $\Delta t^{obs} \simeq 1$ yr imply that the jet in Cen A is mildly relativistic and the time variability is order of year in this keV range of the photon energy. Here we further assume that the same time variability also holds around 150 keV. The parameter $\xi_B = 0.2$ signifies that the equipartition energy in the magnetic field corresponds to 20% of the total luminosity. Using the above values of the parameters, the magnetic field is given by,

$$B = 1.8 \times 10^{-4} \sqrt{\frac{\xi_B}{0.2}} \left(\frac{\Gamma}{4.2}\right)^{-3} \left(\frac{\Delta t^{obs}}{1yr}\right)^{-1} \left(\frac{L_\gamma^{obs}}{3.78 \times 10^{42} erg/s}\right)^{1/2} G. \tag{5}$$

Also the time variability corresponds to a distance scale of $r \sim 2\Gamma^2 \Delta t^{obs} \simeq 10.8\, pc$ which is in the nuclear region of Cen A.

Cen A has a dusty torus within 100 pc of the black hole, with high column density and there can be infrared emission from it. Additionally we also assume that the first peak at around $\sim 4 \times 10^{-4}$ eV in the nuclear SED has contribution from electron synchrotron emission. But for electron synchrotron emission to be operative in this region the time variability is much smaller compared to the one for 150 keV peak and one can consider the minimum variability time scale $\Delta t^{obs} \sim 1$ day [36]. To fix the first peak we keep the bulk Lorentz factor $\Gamma = 4.2$ as before but vary ξ_B and f_{es}. In this case both ξ_B and f_{es} are small compared to their corresponding values for 150 keV . This shows that for low energy peak the synchrotron cooling is very very slow and also the equipartition energy in the magnetic field is very small. As discussed in ref.[24], the energy dependence of the differential photon spectrum for electron synchrotron emission is proportional to $E_\gamma^{-2/3}$ below the break energy $\sim 4 \times 10^{-4}$ eV. In a very recent paper by Araya and Cui[37] it is argued that a diffuse electron population that is uniformly distributed over the entire supernova remnant of Cassiopia A can contribute to radio and infrared fluxes. Also in ref.[38, 39] it is shown that in the infrared region of Cen A the best fitted photon spectral index lies around 0.89 ± 0.25 and 0.84 ± 0.18 which further strengthen the non-thermal synchrotron origin of the infrared emission.

It has been suggested that both radio and X-ray emission in the inner jet of Cen A are produced by relativistic electrons with Lorentz factor $\gamma \simeq 8 \times 10^7$ in 60 μG magnetic field[40]. With our fitted parameters we found that the magnetic field lies very close to 60 μG as shown in Eq.(5) and at the same time the electron Lorentz factor at the break energy is $\gamma \simeq 2.3 \times 10^7$. The maximum observed photon energy for the above Cen A parameters is given by

$$E_{\gamma,max}^{obs} = \frac{9\pi e^2}{8\sigma_T \eta m_e} \frac{\Gamma}{\beta^2} \simeq 1.65\, GeV, \tag{6}$$

where $\eta \sim 1$. If the second peak of nuclear SED is due to electron synchrotron emission, the maximum observed photon energy from this process is 1.65 GeV and the synchrotron photon spectrum is given by

$$\left(\frac{dN_\gamma}{dE_\gamma}\right)_{syn} = \frac{A_e}{2}\left(\frac{1}{C_e E_0}\right)^{\frac{(-\alpha+2)}{2}} \begin{cases} \left(\frac{E_{\gamma,b}}{E_0}\right)^{-\frac{1}{2}}\left(\frac{E_\gamma}{E_0}\right)^{-\frac{(\alpha+1)}{2}} & E_\gamma < E_{\gamma,b} \\ \left(\frac{E_\gamma}{E_0}\right)^{-\frac{(\alpha+2)}{2}} & E_\gamma \geq E_{\gamma,b} \end{cases}, \tag{7}$$

where

$$C_e = \frac{3\pi e}{8 m_e^3} \frac{1}{\Gamma^4}\left(\frac{\xi_B}{2}\right)^{1/2} \frac{1}{\Delta t^{obs}}(L_\gamma^{obs})^{1/2}, \tag{8}$$

and $E_{\gamma,b} = 150$ keV is the break in photon energy corresponding to the break in electron energy. Inclusion of the first break at far-infrared energy in Eq.(7), the condition $E_\gamma < E_{\gamma,b}$ will be replaced by $4 \times 10^{-4}\, eV < E_\gamma < E_{\gamma,b}$. During the period 1991-1995, the observation of Cen A by Compton Gamma-Ray Observatory (CGRO) revealed the break in the spectral energy distribution νF_ν around 150 keV with a maximum flux of about $\sim 10^{-9}\, erg/cm^2/s$[36]. By considering a mean power law index ~ 1.85 the observed luminosity in the energy range 40 keV to 1200 keV is $L_\gamma^{obs} = 3.78 \times 10^{42} erg/s$[30] where the differential photon spectrum can be given by

$$\left(\frac{dN_\gamma}{dE_\gamma}\right)^{obs} = A_\gamma \left(\frac{E_\gamma}{E_0}\right)^{-\lambda}, \tag{9}$$

with $A_\gamma \simeq 5.87 \times 10^{-5}/keV/cm^2/s$. But it is observed that below 150 keV the power index $\lambda \sim 1.8 - 2.0$ and for $E_\gamma \geq E_{\gamma,b}$ it is 2.4 ± 0.28 . The observed spectrum is related to the synchrotron spectrum at the source as

$$\left(\frac{dN_\gamma}{dE_\gamma}\right)^{obs} \simeq \frac{4\Gamma^4 (\Delta t^{obs})^2}{d_z^2} e^{-\tau_{int}}\left(\frac{dN_\gamma}{dE_\gamma}\right)_{syn}, \tag{10}$$

where $d_z = 3.8\, Mpc$ is the distance of Cen A from us, and τ_{int} is the optical depth of photon in the jet. The term $e^{-\tau_{int}}$ in the above equation corresponds to the decrease in observed spectrum due to $\gamma\gamma$ interaction in the photon background of the jet. In this energy range we have observed that $\tau_{int} \leq 10^{-8}$ and does not reduce the observed photon spectrum[41] which is shown in Figure 1 for different observed luminosities. So for low energy, one can neglect the contributions due to $\gamma\gamma$ interactions. Here we use $\alpha = 2.7$ as seen in the diffuse UHECR flux just before the Greisen-Zatsepin-Kuzmin cut off assuming that like proton, electron also follows the same power spectrum. So in Eq.(7), $\alpha = 2.7$ is consistent with the observed with the observed photon spectrum as described in Eq.(9). Comparison of Eq.(9) with Eq.(10) gives $A_e \sim 5.4 \times 10^{12}/keV/cm^2/s$.

In the Inverse Compton (IC) scattering process, the energy of an IC photon is very high and for $40\, keV$ minimum observed photon energy the electron Lorentz factor is $\gamma \sim 6.2 \times 10^7$. So for IC to be operative in this region, the photon
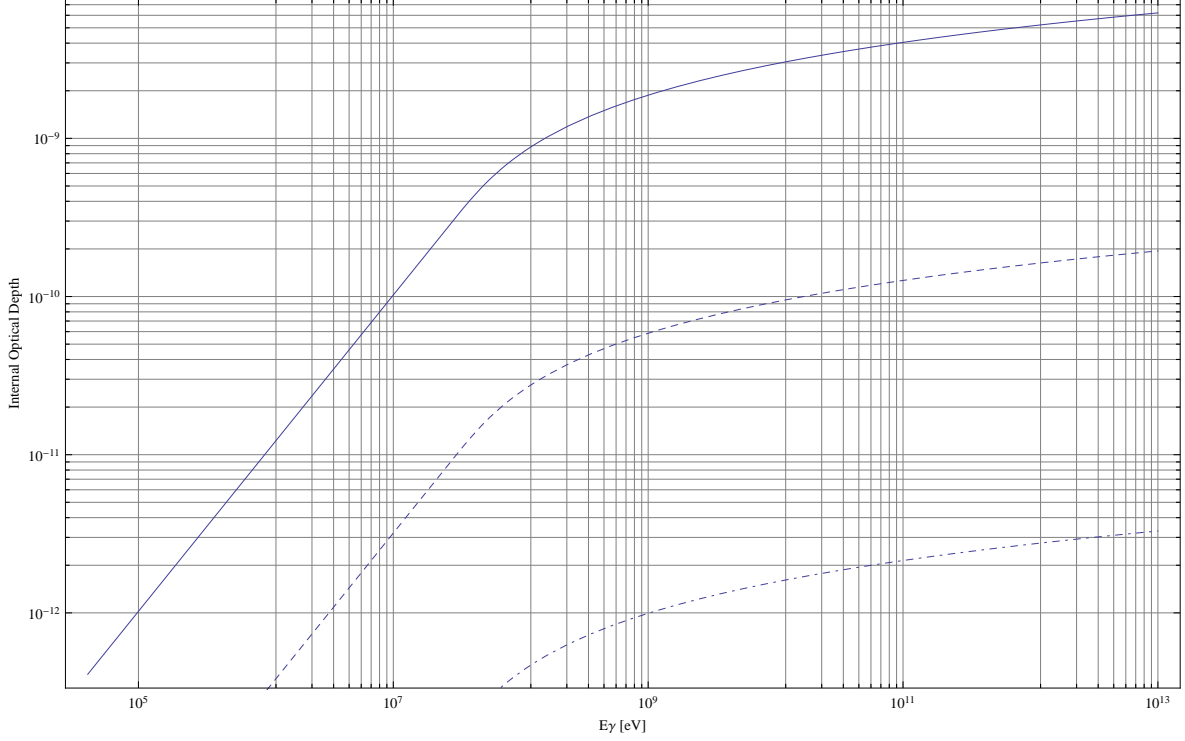
FIG. 1: We have shown the internal photon optical depth $\tau_{\gamma\gamma}$ as a function of photon energy E_γ in the nuclear region of the jet for three different luminosities. These are (a) continuous line is for $L_\gamma^{obs} = 3.78 \times 10^{42}\, erg/s$, (b) Dashed line is for $L_\gamma^{obs} = 1.18 \times 10^{41}\, erg/s$ and (c) Dot-dashed line is for $L_\gamma^{obs} = 2.0 \times 10^{39}\, erg/s$.

energy has to be really very small and for this reason we do not consider the contribution from IC process[32, 42]. The combined OSSE (0.05 - 4 MeV) [36], COMPTEL[43] and EGRET (0.1 - 1GeV) [6] data is fitted by doubly broken power law with two break energies ($\sim$ 150 keV and $16.7^{+27.3}_{-16.3}$ MeV). The spectral indices are $\lambda \simeq 1.74$ for $E_\gamma < 150$ keV, $\lambda \simeq 2.3$ for $150 keV \leq E_\gamma < 16.7^{+27.3}_{-16.3}$ MeV, otherwise $\lambda \simeq 3.3$ for $E_\gamma > 16.7^{+27.3}_{-16.3}$ MeV. But the second break at $E_\gamma > 16.7^{+27.3}_{-16.3}$ has large uncertainty and also the spectrum is almost smooth around and beyond this energy. So in the present analysis we do not take into account for this break and assume that the power index is 2.35 well fitted.

We have shown in Eq.(6) that the electron synchrotron process contributes up to maximum observed photon energy $\sim 1.65\, GeV$. Also in the nuclear region $r \sim 10.8\, pc$, the inelastic collision of Fermi accelerated protons with the background protons will produce γ-rays due to decay of neutral pions[13]. In this case the minimum observed energy of proton is $E_p^{obs} \simeq 5.2\, GeV$ of which about 18% goes to a photon[44, 45] which corresponds to $E_\gamma^{obs} \simeq 0.93\, GeV$. So for $E_\gamma^{obs} \geq 0.93\, GeV$, pp collision will also produce γ-rays and the projectile high energy protons (due to Fermi acceleration) do not have a break energy (the only break in proton energy will come from the proton synchrotron emission which is given by $E_{p,b} \simeq 2.8 \times 10^{27}\, eV$). In the nuclear region the same Fermi accelerated protons colliding with the background photon should also produce photons through delta resonance and its flux can also compete with the one from pp process. By considering the highest detected energy bin found by the Energetic Gamma-Ray Experiment telescope (EGRET) at a break energy $\simeq 200$ MeV [6, 14], we observed that the $p\gamma$ process starts to contribute at energy $E_{\gamma,min} \simeq 1.4$ GeV. But the flux ratio of pp to $p\gamma$ is about $\sim 3.13 \times 10^{14}$ at 1.4 GeV photon energy which increases by a very small amount for higher energies which shows that $p\gamma$ process is negligible and does contribute to the very high energy gamma rays.

In the observed photon energy range 0.93 GeV to 1.65 GeV both electron synchrotron and pp interaction will contribute and the pp contribution can be given by

$$\left(\frac{dN_\gamma}{dE_\gamma}\right)_{\pi^0 pp} = f_{\pi 0 pp} \left(\frac{2}{\delta}\right)^{2-\alpha} \frac{A_p}{\Gamma^{-\alpha}} \left(\frac{E_\gamma}{E_0}\right)^{-\alpha}, \tag{11}$$

where

$$f_{\pi 0pp} = \Gamma \Delta t^{obs} n_p \sigma_{pp}, \tag{12}$$

$\delta = 0.18$ and n_p is the proton density in the jet and $\sigma_{pp} \simeq 4.5 \times 10^{-26}\, cm^2$. The energy normalization we have used here is $E_0 = 1\, GeV$. Around $r \sim 10.8$ pc from the central black hole the proton density can be in the range of $10^4/cm^3$ to $10^6/cm^3$ ref.[13, 32]. Here we consider an intermediate value of $n_p \sim 10^5/cm^3$ and the optical depth of the process is $\tau_{pp} = rn_p\sigma_{pp} \simeq 0.15$, which shows that about 15% of the protons will interact to produce photons. In this energy range the photon power spectrum from both electron synchrotron and pp are proportional to $E_\gamma^{-(\alpha+2)/2}$ and $E_\gamma^{-\alpha}$ respectively. Also it is important to note that we have not observed any break in photon energy around 0.93 GeV and beyond and on top of that the photon power spectrum is well fitted with the index 2.4 ± 0.28 in the energy range 30 MeV to 10 GeV [6]. The EGRET has measured the average flux above 100 MeV (100 MeV to 10 GeV) from Cen A which is $N_\gamma = (13.6 \pm 2.5) \times 10^{-8}\, photons/cm^2/s$ and for $\lambda = 2.35$ the luminosity obtained is $L_\gamma^{obs} = 1.19 \times 10^{41}\, erg/s$. As we have discussed earlier, from 100 MeV to 0.93 GeV, the luminosity is only due to the electron synchrotron radiation which is given as $L_\gamma \simeq 9.24 \times 10^{40}\, erg/s$. On the other hand in the energy range 0.93 GeV to 1.65 GeV, the luminosity from electron synchrotron is $L_\gamma \simeq 1.85 \times 10^{40}\, erg/s$ and from pp is $L_\gamma \simeq 3.23 \times 10^{39}\, erg/s$. Finally the luminosity in the range 1.65 GeV to 10 GeV from pp process is $L_\gamma \simeq 4.69 \times 10^{39}\, erg/s$. So we have to adjust the parameters n_p and A_p so that photon spectrum from pp interaction will overlap with the one from electron synchrotron. But once we fix the value of the parameter n_p in the nuclear region (we take $n_p \simeq 10^5/cm^3$), only A_p has to be adjusted. The observed photon spectrum in the energy range 0.93 GeV to 1.65 GeV is

$$\left(\frac{dN_\gamma}{dE_\gamma}\right)^{obs} \simeq \frac{4\Gamma^4(\Delta t^{obs})^2}{d_z^2} e^{-\tau_{int}} \left[\left(\frac{dN_\gamma}{dE_\gamma}\right)_{syn} + \left(\frac{dN_\gamma}{dE_\gamma}\right)_{\pi^0 pp}\right]. \tag{13}$$

The fitted value of A_p is given by $A_p = 1.8 \times 10^3/GeV/cm^2/s$. Now we shall turn to the high energy range i.e. above 250 GeV in which many collaborations have measured the photon flux and also the spectral index. As we have discussed $p\gamma$ process is negligible compared to the pp process, so only pp process will contribute to the very high energy gamma-ray production in Cen A. For $E_\gamma \geq 250$ GeV only pp process will contribute. But before that we would like to estimate the number of events from PAO which is shown in the next section.

III.   COSMIC RAY EVENTS FROM PIERRE AUGER OBSERVATORY

The Pierre Auger Observatory (PAO) had reported a correlation between ultra high energy cosmic rays (UHECR) and nearby AGN within ~ 75 Mpc[46, 47]. Roughly 10 cosmic ray events are concentrated around the Centaurus direction, a region with a high density of AGNs and two of these events fall within 3 degrees from Cen A suggesting that it could be the first evidence of the UHECR source. Although the composition of these CR events are unknown, we assume them to be protons[16, 21].

In general the intergalactic magnetic field plays a major role in deflecting the CR protons from their original direction. But the deflection angle $\Delta\theta$ is inversely proprotional to the CR proton energy and for a 57 EeV proton it is less than a degree, if we take the intergalactic magnetic field to be of order 10^{-8} G and for higher energy CR protons, the deflection will be still smaller. So the propagation of CR protons from Cen A with energy ≥ 57 EeV are almost ballistic and one can neglect the effect of magnetic field on it.

We estimate the expected number of events from Auger array. For a point source, the integrated exposure of PAO is $\Xi = 9000/\pi km^2$ yr and the integral flux of UHECR from PAO can be expressed as

$$N(> E_{min}) = \frac{\# Events}{Exposure}, \tag{14}$$

where $E_{min} = 57$ EeV. One has to also consider the relative exposure $\omega(\delta)$ for angle of declination δ. For Cen A, $\delta = 47°$ and the corresponding value of $\omega(\delta) \simeq 0.64$[14]. The time duration for the collection of data by PAO is about 15/4 yr between 1st January 2004 and August 2007. So from the above equation we obtain

$$\# Events = \frac{9 \times 10^3\, km^2\, yr}{\pi} N(> E_{min})\, \omega(\delta)\, \frac{15}{4} e^{-\tau_{pp}}, \tag{15}$$

where $e^{-\tau_{pp}}$ is the survival probability of proton due to interaction with the protons in the jet background. Also the integral flux is related to the proton normalization constant A_p as

$$N(> E_{min}) = \frac{A_p}{\alpha - 1} \left(\frac{E_{min}}{E_0}\right)^{-\alpha} E_{min}. \tag{16}$$

Putting Eq.(16) in Eq.(15) and simplifying we obtain

$$\# Events = 5.75 \times 10^2 \times A_{p0}, \tag{17}$$

where we have defined $A_p = A_{p0} \, GeV^{-1} \, cm^{-2} \, s^{-1}$. We can obtain the value of A_{p0} from different observations/Experiments which are discussed in the next section and using these values we can calculate the expected number of events in these observations.

IV. OBSERVATION OF CEN A ABOVE 250 GEV

As discussed in the introduction, Cen A has been observed in almost all wavelengths. Following are the observations of Cen A in Very High Energy γ-rays (≥ 250 GeV) [48–50]. From each observations we have used their given integral flux and calculate the photon normalization constant A_γ as given in Eq.(9) and after that comparing with the observed spectrum of pp process calculate A_p.

1. The H.E.S.S. Collaboration operates an array of four large imaging Cherenkov telescopes to detect Very High Energy (VHE) γ-rays in located in Southern hemisphere in Namibia. Cen A was observed between April 2004 and July 2008 with total live time of 115.0 hours. The measured integral flux above 250 GeV energy threshold was $(1.56 \pm 0.67) \times 10^{-12} \, cm^{-2} \, s^{-1}$ which was around the central region of the galaxy. Also the measured differential photon spectrum is well described by a power-law with the index ~ 2.73 and the normalization constant $A_\gamma \sim 2.45 \times 10^{-13} \, /TeV/cm^2/s$[7]. This gives the luminosity $L_\gamma \sim 2.58 \times 10^{39} \, erg/s$ and $A_{p0} = 0.18 \times 10^{-3}$.

2. In March 1997, with the Durham Mk6 telescope, Cen A was observed for 6.75 hours with a 3σ flux upper limit above 300 GeV of $5.2 \times 10^{-11} \, cm^{-2} \, s^{-1}$[8]. This gives $A_\gamma \sim 1.14 \times 10^{-11} \, /TeV/cm^2/s$.

3. The JANZOS group observed Cen A from New Zealand during April 1988 and June 1989 for 56.9 hours and reported a 95% confidence level upper limit on the flux above 1 TeV of $3.74 \times 10^{-11} \, cm^{-2} \, s^{-1}$ [10] which gives $A_\gamma \sim 1.14 \times 10^{-11} \, /TeV/cm^2/s$.

4. In March and April 1999, Cen A was observed by the CONGAROO 3.8 m telescope for 45 hours with a 3σ flux upper limit above 1.5 TeV of $5.5 \times 10^{-12} \, cm^{-2} \, s^{-1}$ for a point source at the core of the galaxy [11] and this gave $A_\gamma \sim 1.86 \times 10^{-11} \, /TeV/cm^2/s$.

5. In March and April of 2004 further observations were made to Cen A with three 10 m telescopes of the CONGAROO-III array for 10.6 hours. For the core region of Cen A with a 2σ flux upper limit above 424 GeV was $4.9 \times 10^{-12} \, cm^{-2} \, s^{-1}$ [9] and we obtain $A_\gamma \sim 1.94 \times 10^{-12} \, /TeV/cm^2/s$.

In all of the above VHE γ-ray observations we have fitted the differential photon spectrum with the power index $\alpha = 2.7$[7, 51, 52] and calculated their normalization constant A_γ. Comparison of A_γ with the observed photon spectrum from the respective process gives the values of A_p which are given in table 1. Using this A_p we calculate the number of events from these different observations.

It is observed that the H.E.S.S. collaboration results give less than one event during the observation period of 15/4 years. On the other hand during the same observation period the Durham Mk6 telescope, CANGAROO-III, JANZOS and CANGAROO observations could have given respectively 5.06, 0.86, 16.61 and 8.26 events in PAO due to pp interaction in Cen A. So our analysis shows that many UHECR protons from Cen A can be observed by PAO.

V. CONCLUSIONS

The Cen A is observed in almost all the energy band and its nuclear SED shows two peaks of which one is around 150 keV and another is in the far-infrared band. In this work we assumed that the peak around 150 keV is due to the electron synchrotron radiation and adjust the parameters Γ, ξ_B, Δt^{obs} and f_{es} so that the observed photon energy E_γ^{obs} is 150 keV. In this fitting we have $\Gamma = 4.2$ and $\Delta t^{obs} = 1$ yr correspond to the fact that the jet is in the nuclear region $r \sim 10.8$ pc and it is mildly relativistic which is being observed in Cen A. The magnetic field obtained around

TABLE I: Observation of Cen A by different Experiments with their respective lower observed photon energy limits are shown here. We also show their corresponding proton normalization constant and the expected number of CR proton events.

Experiment [ref.]	E_γ	A_{p0}	# Events
H.E.S.S.[7]	$\geq$ 250 GeV	0.18×10^{-3}	0.1
Durham[8]	$\geq$ 300 GeV	8.81×10^{-3}	5.06
CANGAROO-III [9]	$\geq$ 424 GeV	1.5×10^{-3}	0.86
JANZOS [10]	$\geq$ 1 TeV	28.9×10^{-3}	16.61
CANGAROO [11]	$\geq$ 1.5TeV	14.38×10^{-3}	8.26

the nuclear region is about 180 μG[40]. We found that the IC process does not contribute to the observed photons in the GeV-TeV range. In our model the maximum energy up to which the electron synchrotron contributes is 1.65 GeV and the other process which contributes to high energy (1 to 10 GeV) to very high energy ($\geq$ 250 GeV) is the pp process. Unfortunately the $p\gamma$ process is very small compared to the pp process.

We compared the observed photon spectrum from different observations by taking the spectral index $\alpha = 2.7$ with the calculated one from the pp process, which determines the normalization constant A_p for the cosmic ray (CR) protons. We use the A_p from these observations to calculate the number of events from PAO and found that indeed many CR protons above 57 EeV can arrive on Earth from Cen A. In a recent paper in the context of Cassiopia A, a young supernova remnant, Araya and Cui[37] have also independently come to the same conclusion that synchrotron emission from the electron can account for the radio to X-ray emissions and additional hadronic component is needed to explain the GeV emission thus providing evidence for the production of cosmic rays.

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